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Psychological Bulletin

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CONTENTS

General Reviews and Summaries:

Vision — General Phenomena: L. T. Troland, 201. *Hearing:* R. M. Ogden, 228.

Books Received, 238; *Notes and News,* 239.

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THE

PSYCHOLOGICAL BULLETIN

GENERAL REVIEWS AND SUMMARIES

VISION—GENERAL PHENOMENA[1]

BY LEONARD THOMPSON TROLAND

Harvard University

Not the least of the contributions to scientific knowledge due to the war is to be found in the firm establishment of Henschen's theory of the point for point representation of the retina upon the calcarine cortex. A very comprehensive article by Best (13) summarizes the results of studies upon disorders of the visual function due to war injuries of the central optical apparatus. He first contests Igerscheimer's doctrine that all injuries to the optic nerve tend to produce scotomas centering about the blind spot, and then reviews the evidence for the specific localization of various visual functions in the cortex. The calcarine fissure is the center of relative binocular localization, being responsible for the establishment of visual direction and the combination of disparate sensations. All the evidence is in favor of a point to point representation of the retina in this region, and hence is contrary to von Monakow's idea of a diffuse distribution of the optic connections. Psychologically higher visual functions, such as motion perception, contrast processes, visual recognition, perception and imagination, and certain aspects of color sensibility are dependent upon centers physiologically higher than the calcarine region. Destruction of this latter region has no more serious an effect upon the general visual consciousness than has destruction of the retina or optic

[1] A very large amount of foreign war-time literature not hitherto available but now at hand is necessarily neglected in the present summary on account of limitations of space. I have here confined myself strictly to articles dated for the year 1919. I hope to be able to summarize previously unreviewed literature, at least for the years 1917 and 1918, in a supplementary summary.

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nerve. A careful study of this paper is recommended to anyone interested in a thorough analysis of the dependency of various visual functions upon the brain processes. Morax, Moreau, and Castelain (73) report results of a study of visual defects in 86 cases of wounds in the occipital region of the cortex, dividing these cases into seven characteristic groups. Among these cases there was only one in which complete blindness was caused by an occipital lesion, vision always tending to remain in the fovea except where both cerebral hemispheres were seriously damaged. Morax (72) continues with a theoretical discussion of the cerebral localization of macular vision, on the basis of the data accumulated by himself and his collaborators. He finds that the cortical center for macular vision is distinct from that of peripheral vision although contiguous with the latter, lying posterior to it in the calcarine fissure. The macula is divided into two halves, each of which is represented on one hemisphere only. The entire *fovea*, however, has a representation on both hemispheres, the centers for the fovea lying posterior to those for general macular vision on the edges of the calcarine fissure. Monbrun (71) summarizes results of studies upon war injuries to the visual cortex which confirm those of the investigators above considered. He finds the visual projection area to be limited to the lower portion of the cuneus and the upper portion of the lingual lobe within the calcarine fissure and strongly supports Henschen's theory of point to point retinal representation. A partial destruction of the cortex in this region produces a scotoma with definite limits within which there is absolutely no vision. Like Morax he finds the macula to be projected on the posterior surfaces and the periphery of the retina on the anterior ones. However, there are wide individual differences in the cortical representation of the macula. Although the perceptions of light, form and color may be differently affected in different stages of hemianopia the projection of these three functions upon the calcarine cortex appears to be identical. The probable paths of the optic fibres from retina to cortex are discussed in some detail. Wilson (99) reports 5 cases of local scotomas determined by wounds in different portions of the occipital lobe which present evidence in favor of Holmes' view that the vertical axes of the visual field are represented in dorsal and ventral margins of the visual projection areas.

Schweinitz (87) analyzes the visual disorders resulting from war psycho-neuroses. General loss of visual power and enfeebling

of color vision often occur, as well as disturbances of the motor functions of the eye. There may be a reduction of acuity, cloudiness of vision, or constriction of the visual field, but in practically every case the symptoms are characteristic of a psychological situation rather than of an anatomical injury and the patient usually behaves in such a manner as to avoid bodily injury although his visual consciousness is seriously curtailed. Disorders of this sort would appear to be determined by affections of visual processes in the association areas of the cortex rather than in the primary occipital region. Hoeve (**52**) contests Igerscheimer's view already referred to above regarding the results of injuries to the optic nerves or tracts. The arrangement of the fibers in the optic nerve is such that injuries to the latter should be expected to produce scotomas having a position in either the monocular or binocular visual fields roughly corresponding with the positions of the lesions in the nerve cross-section. Well known types of scotomas due to optic nerve injuries do not center in sector form about the blind spot, as claimed by Igerscheimer, whose views are neither theoretically nor clinically defensible. Spaulding (**91**) describes two interesting instances of scintillating scotoma, observed upon himself, which seem to be associated with abnormalities in refraction.

A considerable number of studies of the motor and refractive functions of the eye are reported. Stefanini (**92**) discusses the movements of the eyes in response to sounds produced on opposite sides of the head. He finds a reflex tendency of the eyes to follow the sound, even when the displacement of the latter is subjective and due to binaural beats. Lamb (**64**) notes that the only practical application of the mathematical "theory of finite rotations" is to the movements of the eye-ball. He presents a new mathematical analysis of these movements which is simpler in form than that of Helmholtz, with which it is critically compared. He concludes that "the cardinal advantage of the fact that the eye conforms to Listing's law . . . consists in this, that the test of superposition is fulfilled for straight lines which pass through the center of the field of view, in the primary position." Liddell (**65**) examines experimentally the validity of Ferree and Rand's theory that so-called fluctuations of visual attention are due to eye-movements. Photographic records of the eye-movements of seven subjects were secured during such fluctuations, and no correlation was found between the movements and the phases of visibility and invisibility of minimal visual stimuli. The results are deemed to refute the

views of Ferree and Rand, which were based upon less adequate data.

Weve (97) contests Behr's theory that stimulation of the nasal half of one retina tends to cause a *direct* pupillary reaction only, while stimulation of the temporal half tends more towards a *consensual* response. Observations upon twelve subjects show clearly that direct and consensual reactions are brought out to the same extent from both retinal regions. The literature dealing with the pupillomotor function is reviewed and various possible arrangements of the pupillomotor paths in the optic tract are outlined. Abelsdorff (1) describes a case of war injury to the optic nerve, resulting in a peripheral but no central scotoma, in which the pupillary response was destroyed. Since central vision was intact, he argues for the existence of special pupilomotor fibers, distinct from those responsible for sensation. Engelking (30) has determined the minimal brightness necessary to produce a noticeable pupillary reaction, using both photographic and entoptic methods of observation. After twenty minutes dark adaptation the first intimation of response appeared at an illumination of 0.001 meter candles, but a positive reaction was not obtained until 0.025–0.04 meter candles were reached. The latter value corresponds with the absolute threshold of cone vision. Engelking concludes that a slight, faltering, pupillary response is aroused by stimulation of the retinal rods, but that the function rests mainly upon the cones. A large stimulus field, 23.0 by 16.3 degrees, was employed. French (38) reviews the physiology of the eye, and then presents new data concerning the relation between pupillary area and the intensity of the stimulus. He finds the equation, $A = kI^{\frac{1}{3}}$ to hold for these two factors, k being a constant.

Hartridge (45) endeavors to explain the fact that the focal length of the crystalline lens is noticeably shorter than what would be expected from its form and refractive index, by pointing out that the increasing optical density of the lens towards its axis will bend the wave-front of the light by differential retardation, as it moves through the lens substance, this effect being added to the refraction which occurs at the surfaces. The same investigator (44) discusses aberrations of the ocular refractive system which affect peripheral vision. The curvature of the retina is found to compensate quite perfectly, up to 30 degrees (at least in the rabbit's eye) for that of the field of the lens, the size of an image being practically independent of angle, a necessity for stereoscopic vision. Lock-

wood (**66**) finds that with a pupil larger than four millimeters in diameter the spherical aberration of the eye appreciably influences distinctness of vision, and with a fully dilated pupil the difference in refracting power between the central and edge zones amounts to 6.6 diopters.

Bailliart and Magilot (**6**) outline a method for determining the blood pressure in the vessels of the retina, and find this ordinarily to lie between 15 and 30 millimeters of mercury. Osborne (**75**) has examined the aqueous humour of the ox's eye and finds it to be practically free from protein, although otherwise resembling blood serum in constitution. This freedom from protein increases transparency, but can only be explained on the assumption that the containing membranes are waterproof or are in a state of œdema. Descemet's membrane is probably waterproof, but the iris is not, and so the aqueous humor must penetrate the latter with a pressure of about 10 millimeters of mercury. Nordensson (**74**) finds that the transparency of the anterior boundary of the vitreous humour decreases progressively with the age of the subject, being practically constant for all individuals of the same age.

Sheard (**89**) and Raman (**80**) discuss, independently, the causes of the scattered light phenomena seen about small luminous areas in the dark; and arrive at strikingly similar conclusions. Raman first questions Helmholtz's view that these are mainly due to diffraction at the edge of the pupil, and shows by means of a square artificial pupil that the pupil effect, although present, is relatively small, the principal phenomena being independent of the pupil. The halos which are observed strikingly resemble those caused by the diffraction of light passing through a layer of irregularly placed small particles, such as lycopodium powder. In harmony with this interpretation, the use of monochromatic instead of white light brings about marked changes in the phenomena produced by the eye. The two halos which are visible indicate the operation of two sets of particles, of average diameters 13 μ and 7 μ, respectively. Sheard's findings are in general agreement with the above: the first colored halo is attributable to the cells in epithelium of Descemet's membrane, the red component of this halo having an angular diameter of 3° 40′; the second halo, which is much fainter, has a diameter of 8° and is probably due to the epithelial cells of the cornea. The sizes of the particles theoretically required to produce the observed effects are calculated to be 10 μ and 25 μ, respectively, and these sizes agree approximately with those of the epithelial cells.

In the field of *ocular hygiene;* Hartridge (42) finds the cause of eye-strain to be the attempt to dissociate the reflexes of accommodation and convergence. Eyestrain cannot be due to too great exertion of the accomodative mechanism alone, since it is as common in conjunction with myopia as with hypermetropia. Experiments, with accomodation accomplished by a spectacle lens but convergence still required, produce eyestrain—and to an extent proportional to the success with which the diplopia is overcome. Coblentz (21) presents the spectral transmission curves of various glasses designed to protect the eyes from injurious radiations, such as the ultra-violet and infra-red. Ferree and Rand (35) follow out previous investigations on the power of the eye to sustain clear and comfortable seeing with different illuminants. In the present paper they study the influence of various proportions of ceria and thoria in gas mantles, and find that in general the efficiency of the eye increases with increase in the per cent. of ceria. 3 per cent. of ceria, however, is somewhat better than 5 per cent., which was the highest amount tested. Mantles lacking in ceria produce a greener light than those containing it in some quantity. The results of the tests are presented in numerical and graphical form.

Ferree and Rand (34) also report measurements of the time required to change the adjustment of the eyes for clear seeing at a near point to one six meters away, and *vice versa.* Only the motor factors in the process are dealt with, since other work by the same authors shows that the lag of the sensory changes is relatively very small. For 18 normal observers, the times for passing from the near to far points varied from 0.50 to 1.16 seconds, and for the reverse adjustment between 0.39 and 0.82 seconds, 15 of the observers requiring more time for the first change. The modal time for the double excursion lies between 1.35 and 1.65 seconds. Two types of apparatus were employed and the results are tabulated in full. A small amount of astigmatism has a marked effect upon the efficiency of this function. Forsythe (37) has determined the minimal speed for telegraphic light signaling, as limited by the inertia of the eye. The best ratio for dot: dash: space is 1:4:3. At a distance of 2,700 yards, the minimal time for a four part signal is about 1.6 seconds, both in daylight and at night, although some observers do slightly better in daylight. A gas-filled ribbon filament tungsten lamp, turned on and off electrically is as effective for such signaling as a shutter. Prantl (78) has studied the speed of reading, with the type at various angles to the ocular

horizontal. His graph of the time required with respect to the angle shows two maxima, at 150 and 210 degrees, respectively, in these positions four times the normal time being demanded. At 180 degrees (with the type up-side-down) only 3.7 times the normal is needed. The various factors involved in reading speed are discussed.

Griffiths and Baumgartner (41) have investigated the relation between power to visualize, as tested by the ability to make geometrical constructions mentally, and fineness of brightness discrimination as determined by ability accurately to set a photometer, hoping to throw some light upon the basis of individual differences in image type. Data from 75 subjects however show only a very low correlation between the two traits, not enough to warrant the supposition of a causal linkage. There is no correlation at all between memory for letters and digits, or speed of multiplication, and brightness discrimination.

Wingender (100) describes experiments upon many classical geometrical optical illusions by an interesting method. The main lines of the figures were shown by reflected light, while the supplementary lines—inducing the illusion—were added at will by transmitted light. When this addition was made a motion of the main lines, such as to generate the illusion, could usually be seen. A rapid alternation of these two phases of the figures shows that there is a minimal period, about one fourth of a second, required for the illusion to develop; and this time is shown to be the same as that needed for the change from a monocularly conditioned to a binocular stereoscopic perception. It is clearly much greater than that needed for a purely sensory arousal. The general and special conditions for the generation of many well-known illusions, such as those of Muller-Lyer, Zöllner, Hering, etc., are carefully considered: sharp analysis of the figure, and complexity too great to be appreciated as a whole are detrimental to the illusory effects, and the position of the fixation point is of importance.

Henning (50) discusses at great length the reasons why the sun and moon appear larger at the horizon than at the zenith. Observations made by sixty observers in the open indicate that the principal cause of the apparent magnification lies in the red color assumed by the celestial orbs in rising or setting. Not only the sun, moon or stars, but all objects on the horizon which fall within the zone of the reddish glow are subject to the magnification, and the increase in the clearness of details is sometimes as great as

would result from use of a powerful telescope. The illusion is reduced or destroyed by observing through red-absorbing glasses. The mechanism of the effect is as follows. The preponderance of red rays, on account of their relatively slight absorption by smoke or vapor, reduces the "atmosphere" of the scene, thus making it appear stereoscopically nearer and sharping its details. The principles involved in the Aubert-Förster and Köster phenomena demonstrate a linkage between acuity, apparent size and apparent brightness, such that increased acuity carries with it increased apparent size but decreased apparent brightness. The celestial magnification effects are instances of these phenomena; the augmented size of the sun and moon at the horizon is found to entail a diminished luminosity. Neither the size nor the luminosity changes are physical. Other principles which may be involved in the illusion are considered in detail, together with the basis of allied appearances, such as distortions of the sun or moon at the horizon, the apparent shape of the arch of the heavens, etc.

Wassenaar (**94**) finds that the vessels of the retina can be seen entoptically projected upon a rotating black and white disk, the color of the entoptic images varying with the speed of the rotation. It is sometimes purplish red and sometimes green. Streaming movements, attributed to the vessels of the choroid, can be observed by a similar method. The same investigator (**95**) discusses the colors which are generated by alternately covering and uncovering the closed eye.

Bard (**9**) is not satisfied with explanations which have been advanced hitherto for the invisibility of the blind-spot. He notes that at the *punctum cæcum* the layers of the retina do not stop suddenly but with undulations, and that corresponding distortions are observable in objects in the vicinity of the blind spot. The undulations of opposite sides are supposed to be dovetailed in their projection upon the cortex or visual field. The same writer discusses anew the mechanism of localization in visual space, finding the simple "geometrical" theory of private line conduction from the retina to the cortex to be inadequate because of poverty of conductors and lack of specificity in the functioning of individual conductors. He believes that each retinal receptor possesses mechanisms which are analytic for direction or position and which impress upon the optic nerve currents, characteristics utilized by the cortex in sorting the impulses spatially. This view is discussed in comparison with classical "local sign" doctrines. In another paper (**8**)

Bard considers the same general problems not only for vision but for audition and touch. Depth perception is not mainly a binocular function, as usually supposed, but depends upon the fact that the monocular retinal image has a thickness, positions within which are sensed by a mechanism which is "natural and immediate."

Eaton (**28**) analyzes the various monocular criteria of depth, and contends that since monocular vision gives the impression of solidity, it should be called stereoscopic. He finds that the fusion of disparate images is not essential to stereoscopic vision and that its deliverances are even capable of being overcome and reversed by other, and monocular, factors; as in the case of interchanged stereoscopic photographs of familiar objects. In securing a stereoscopic effect, monocularly, from a single photograph it is important that the perspectives of the eye and camera should coincide. The decrease of the sharpness of images with increasing distance is an important factor, as shown by the difficulty often experienced in correctly fusing steresocopic X-ray photographs where this relationship is reversed. Previous experience is the most important of all determining influences. In general the combined power of so-called secondary criteria of depth (perspective vision) is greater than that of the "primary" binocular mechanism. In a second paper (**29**) Eaton analyzes some of these factors in greater detail. He adduces evidence to show that very seldom does our perception utilize simultaneously all parts of both retinal images, and that the determination of corresponding points is not hereditary but is fixed by experience. The principles involved in the fitting together of the two retinal images are discussed in considerable detail, and the functions attached to the separate eyes are found to remain independent until the very highest levels of synthesis are reached. Luster, binocular or monocular, is due to the presence of light in addition to that required for the adequate perception of an object by itself. Other suggestions, of interest to the close student of binocular functions, are offered. Barrie (**10**) disagrees with Eaton as to the effects obtained by various rearrangements of ordinary stereoscopic photographs, finding the binocular factor to be more powerful.

Kaila (**61**), in a lengthy article, endeavors to build up an empirisistic theory of depth perception in which the disparation of binocular images acts as a "reproduction motive" entering into an association complex based upon experience and containing the final stereoscopic impression. Hering's theory, involving the

automatic fusion of two genetically determined depth sensations, is found to be inconsistent with the fact that equal amounts of diplopia may arouse quite different depth impressions if other factors in the general sensory constellation are permitted to vary. In the developed perception the diplopia is of course subconscious, but this does not prevent it from acting as an associative unit. The problem of the cerebral mechanism of this association is considered in some detail, together with the question as to the manner of co-representation in the cortex of corresponding retinal points. The position of the binocular fixation or convergence point, recorded by oculomotor impulses, must also enter into this associative system as a parameter. The theories of the Panum and of the Hering depth phenomena are considered very carefully, and there is an appendix containing a long critique of Jaensch's doctrine of space perception. Cohen (**24**) describes an apparatus designed to test stereoscopic vision at considerable distances (30 to 40 feet from the subject). It consists of a dark box displaying an arrangement of four, colored, letters at different distances, the observer being required to state their order.

Kuile (**63**) offers a mathematical analysis of the apparent motion generated by the binocular fusion of two synchronous, simple, harmonic motions independently presented to the two eyes. The motions occur symmetrically, parallel to a line joining the nodal points of the eyes. The stereoscopically generated motion has an elliptical, circular or hyperbolic path, according to the exact conditions selected. The relative velocities of the apparent motion at various points are calculated and a chart providing an empirical verification of the results is given. Koffka (**62**) also applies mathematical methods to problems of motion perception. Beginning with Korte's empirically established laws which express the relations between intensity, distance and time interval for the optimal motion impression in stroboscopic vision, he uses Wertheimer's theory of the neural "short-circuit" to develop equations for the brain process underlying such vision. The argument is very elaborate, and leads not only to a theoretical analysis of the brain mechanism but also to definite predictions regarding stroboscopic phenomena, which are compared with empirical findings.

Roelofs and Zeeman (**84**) have made an experimental study of factors controlling the periods during which disparate contours, in retinal rivalry, are visible. Conflicting vertical and horizontal, and other more complex contours were used. Greater acuity of

one eye as compared with the other, greater contrast with the background, greater intensity, and eye-movement parallel to the given contour tend to cause predominance. Rivalry is interpreted as a phenomenon of passive attention. The conflict is one of configurations, as such, and not of eye-fields.

Gibson (**39**) discusses further the similarity between color comparisons made by a normal subject in a "minus red" light and those made by the dichromatic color-blind in ordinary illumination. Because certain dyes employed to color wools are fluorescent it is necessary to place the "minus red" filter between the wools and the eye to produce exactly similar confusions. Cowdrick and Winfield (**25**) have determined the best conditions for the use of the Hering color-blindness apparatus, which were never specified by its inventor. They find that when artificial daylight is employed at a constant intensity it permits a reliable diagnosis of different types of color-blindness. Rich (**81**) finds that the commercial "daylight" lamp (Mazda C2) departs too much from actual daylight to warrant its use in establishing color-matches for careful research purposes, although it suffices for demonstration of the laws of color-mixture in laboratory courses. The marked deficiency of the artificial light in blue, as compared with daylight, makes itself felt when colors in the short wave end of the spectrum are combined with others.

Luckiesh (**69**) offers a general outline of the conditions for successful terrestrial, marine and aërial *camouflage*, in which he utilizes the principles of the psychology and physiology of vision. In a second more lengthy paper (**68**) he discusses the problem of the visibility of aëroplanes. This profusely illustrated article carefully analyses the problem on the basis of physiological and physical optical principles, and many actual measurements made from aeroplanes of the brightness and other visual values of various types of terrestrial surfaces, and also of sky and clouds. Jones (**60**) attacks the problem of camouflage in its application to the protection of vessels against submarines, considering in particular the "low visibility phase of protective coloration." He analyzes theoretically the various factors involved and develops a formula for expressing the visibility of an object in terms of the brightness of its background and of the veiling glare necessary to just make the object invisible. An instrument is described which measures visibility in accordance with this principle, which was used in elaborate experimental tests made with model ships variously

camouflaged. Photographs of the experimental "theater" employed in this work are published in another place (*Trans. of the Illum. Eng. Soc.*, 1919, 14, 232–233.) Results of these measurements are reported in detail and their analysis shows that broken colored systems the elements of which can be perceived increase visibility, while if they are too small to be seen they have no effect. Visibility depends entirely on the average hue, saturation, and brightness values of the object in contrast with its background The best values of these several factors for characteristic weather conditions are specified. Gibson, Tyndall, and McNicholas (**40**) present graphs of the spectral transmissions of various filters which were used during the war to detect camouflage or to improve visibility.

In the field of *photometry* Ives (**58**) offers a specification of a standard photometric scale analogous to the thermometric scale employed in pyrometry. The various factors involved are (1) conditions of observation: a field brightness of 2.5 millilamberts, field size of 2°, and the flicker photometer, (2) the method of choosing observers based upon specified test filters, (3) the visibility curve, (4) the mechanical equivalent of light: 0.00156 watts per lumen, (5) standards of luminous intensity, and (6) standards of color. The specification of all of these factors is based upon the most recent data of the author and other investigators. Blondel (**14**) describes a system of physical photometry similar to that previously reported by Ives. He employes a spectroscope with a template, representing the visibility curve, in the plane of one of the slits and a thermopile to measure the intensity of the combined rays. He describes this arrangement as the "inverse" of that used by Ives.

Hyde, Forsythe and Cady (**55, 57**) find that Coblentz's energy distribution curve for the acetylene flame is such that a color match between it and a black body could not be made with an accuracy greater than 7 to 8 per cent. Measurements made by the present investigators and others, however, show that a close color match is actually obtainable, the corresponding black body temperature being 2360° K. Coblentz (**22, 23**) defends his work on this subject by pointing out that only very low precision of measurement is obtainable in the blue and violet end of the spectrum but that elsewhere his data correspond well with the above mentioned black body temperature. He offers a table of revised values. The importance of this question lies in the fact that practically all measurements of the visibility curve have been made with the acetylene flame.

Hyde, Forsythe and Cady (**56**) present a new experimental determination of the brightnesses of a black body at temperatures between 1700 and 2600° K. The empirically obtained values agree well with those computed from the visibility data previously published by the same investigators and based upon direct comparison rather than flicker photometry. The same data also provide the basis for a new estimation of the mechanical equivalent of light as 0.00150 watts per lumen. The value of 70 candles per sq. cm., or the brightness of a black body at 2077° K. (color match with a 4 w.p.c. standard carbon lamp), is proposed as an absolute standard of light.

A number of papers deal with practical tests of vision designed for the *selection of aviators* or other military recruits. Cantonnet (**16, 18**) lists seven visual requirements which the aviator should meet and describes tests for each of the visual functions involved. Novel tests for "quickness of acuity" and sensitivity to dazzling are outlined. Methods of testing night acuity and dark adaptation are also presented. The same author (**17**) describes a binocular vision test designed to measure any deviations from normal of the convergence of the eyes with fixation of objects at various distances. Howard (**54**) discusses the various factors involved in the visual judgment of distance. An apparatus is described which tests individual sensitivity to change in "binocular parallax" and in the size of the retinal image. Results are given for 106 subjects, 75 of whom were aviators. Binocular parallax is found to be twenty times more important than the size of the retinal image in judging distances under conditions which were used. The normal threshold for the detection of binocular parallax is 8.0″, but 14 observers had an average threshold as low as 1.89″. The reaction time for monocular judgments is much higher than for binocular ones, which latter are practically instantaneous. There is very little correlation between the parallax threshold and visual acuity. Spearman (**90**) and others discuss briefly various visual factors involved in the efficiency of the aviator.

Cobb (**19, 20**) reports quantitative studies of the process of dark adaptation with special reference to the problems of night flying. An apparatus was designed which permitted a determination of the absolute luminosity threshold at various times in the course of dark adaptation. After the subject had become completely dark adapted his eyes were dazzled for five minutes and later for fifteen seconds and the courses of the adaptation after each of these

exposures were studied. The absolute peripheral threshold at equilibrium dark adaptation was found to vary from 1.34 to 9.95 millionths of a candle per sq. cm., the mean value for 15 subjects being 4.97. The recovery of dark adaptation after the fifteen seconds exposure was three times as fast as after the five-minute exposure. There was little correlation between rate of adaptation and the final level attained, and no correlation was found between power to discriminate brightnesses and any adaptation factor. A statistical subdivision and classification of the individual results is presented. Plateaus in the adaptation curves suggest the existence of two factors in the process.

Downey (27) describes a new adaptometer and photometer which utilizes a luminous radium compound as a standard comparison stimulus. The device permits a systematic investigation of the course of dark adaptation, the proper procedure for which is outlined. Tests with this instrument lead to the following conclusions. Dark adaptation of one eye has no effect upon the other, although under similar conditions the rate of adaptation is the same for both eyes. There is no binocular summation of brightnesses in dark adaptation. Recovery from such adaptation is complete in about thirty seconds, after which the same time is required to reproduce the original adaptation as in the beginning, provided bright daylight is employed all over the retina, although when only a small field is used to reduce the adaptation to the daylight level recovery occurs in about a minute. There is a marked dark adaptation in the macula, and even in the rod-free area of the retina. Dark adaptation has relatively little effect upon the threshold for extremely small stimulus fields.

Buisson (15) offers a new account of his measurements on the minimal quantity of radiant energy which will produce vision.

Putter (79) continues the development of his general, mathematically formulated, theory of stimulation. In the present contribution he applies the principles previously deduced to the temporal relations of excitation in the human eye. The laws of fatigue or "*Umstimmung*," and of the growth and decay of visual sensation are derived theoretically and compared with empirical findings. Equations, tables and graphs are given showing the temporal course and limits of the fatigue process, the data of Von Kries and Schjelderup being employed in combination with the theoretical relationships. A similar treatment of the facts relating to the growth or "Anklingen" of the sensation is based upon the

results of Exner and of Martius. A further contribution, the final one of the series, deals with stimulation processes in general, but some particular visual phenomena are considered. These articles seem worthy of a more detailed study than the reviewer has yet been able to give them.

Filehne (**36**) discusses certain phenomena which are most readily observed under conditions of twilight vision. Among these are the vibrations of the atmosphere due to temperature differences and movements of thin clouds of vapor such as result from evaporation. Observations upon these phenomena indicate that the rate of decrease of the sensibility of the retinal rods within a circular central field, 2 to 5 degrees in diameter, with increasing brightness of the retinal image is greater than in the remainder of the retina. Experiments on the appearance of a sphere illuminated so as to exhibit a bright crescent and subtending a visual angle of about 3 degrees show that the crescent may cause the general illumination of the sphere to disappear, this being due to the reduced sensibility of the retina in the region concerned. This observation is applied to the appearance of the planet Venus, on which general faint illumination in the crescent stage cannot be seen against a completely dark sky but only in twilight. Bell (**12**) reports measurements on the visibility of bright lines and spots. Previous investigators disagree widely as to the smallest angular size of the single spot or line which is visible. In the case of a bright object on a dark background the threshold appears to depend only on intensity, stimuli subtending angles as small as 0.2″ often being visible. The present investigator made tests with German silver wire against a dark background and found the minimal angles to vary from 2.3″ to 0.46″, depending on the nature of the reflection from the wire and that of the background. White thread against a background of black paper was distinctly visible in sunlight at 0.92″, the lowest angle at which any portion could be distinguished being 0.46″. The brightness contrast in this case was 16 to 1. This was less than 1/50 the minimal angle for a single spot under similar contrast conditions.

Roelofs and Zeeman (**85**) discuss a possible interpretation of certain cases of night blindness. They estimate the intensity of starlight illumination at 0.0003 meter candles. The visual acuity at this and higher intensities was determined, a relatively slow increase of acuity with respect to illumination being found. Since refractive errors in the eye increase the intensity required for a

given acuity the illumination obtainable at night may for individuals with high refractive errors be insufficient to permit adequate seeing, especially with the large pupil which goes with night vision.

Allen (2) reports extremely interesting results of a continuation of his earlier studies on the effect of differential color fatigue upon critical flicker frequencies. His findings "appear absolutely to determine the number of fundamental color sensations." The eye was first fatigued for three minutes with a selected monochromatic radiation, after which—in separate experiments—the critical flicker frequencies for this and other spectral wave-lengths were determined so that curves representing the spectral distribution of these frequencies after fatigue by different monochromatic stimuli could be plotted. In general fatigue lowers the critical frequency, but not equally for all colors, and certain fatiguing stimuli produce no effect upon the spectral curve. There are four points in the spectrum yielding such stimuli, lying at 660, 570, 470 and 420 $\mu\mu$ respectively. The effect of fatigue by stimuli lying between these points in the spectrum may be either to decrease the critical flicker frequency in a single spectral region or in two such regions, as the case may be. For example, fatigue with yellow, 577 to 651 $\mu\mu$, causes a decrease in the frequency for red and also for green but little decrease for this yellow itself. The spectral regions from which fatiguing stimuli produce no effect upon the frequency curve are regarded as fundamental transition points, and a comparision of these regions with the color sensation curves of Abney, and König and Dieterici reveals a close correspondence with the ends or intersections of the component color curves in question. Fatiguing stimuli which produce only one depression in the frequency curve are regarded as mono-sensational. Data from color-blind eyes corroborate these interpretations and substantiate the three-color theory with its implication that yellow is a compound sensation.

In a second article (3) Allen presents new data bearing on the relation between critical flicker frequency and stimulus intensity. Spectral stimuli were employed, and the results confirm those of Haycraft, who found the critical frequency to be proportional to the logarithm of the brightness, with a shift in the constants of the equation at intensities corresponding with the threshold of cone vision. The relation of the results to the Purkinje effect is carefully considered. Piéron (76) discusses the law relating stimulus intensity, i, with the time, t, required to reach the maximal sensory intensity. The law of Bloch, $i\,t = constant$, holds only for short

times. That of Hoorweg-Weiss, first applied to the electrical excitation of the nerve but rediscovered by Blondel and Rey for visual sensation, is much more satisfactory and has the form $t = a/(i - b)$, a and b being constants, the interpretations of which are considered. Another fairly successful relationship is $t = a/i^n$, n having different values for different departments of sensation. The law of Hoorweg-Weiss is found to hold to within about 2 per cent for eight different kinds of sensory stimulation as well as for several objectively measured nerve processes. Woog (**101, 102**) reports experiments on the persistence of vision in different regions of the retina. He finds an increase in flicker towards the periphery, using a frequency of 15 to 25 per second, persistence therefore being greatest in the center of vision. His stimulus fields when gradually brought nearer to the eye began to flicker when they subtended an angle of about 9°. In answer to an objection that the greater sensitivity of the periphery to flicker may depend upon the exact level of intensity which was used, Woog states that the interposition of dark glasses between the eye and stimulus surface does not alter the relationship.

Ferree and Rand (**32, 33**) present new measurements of the chromatic thresholds of sensation from the center to the periphery of the retina and discuss the bearing of their results upon color theories. Supporters of the Hering theory have claimed that the sensitivities to red and green fall off in a constant ratio towards the periphery, the same being true for blue and yellow. The results of the present investigation do not confirm this view. Spectral red, yellow, green and blue stimuli were employed and the chromatic thresholds were measured in energy units at approximately twenty-five different visual angles, ranging from 0 to 92° in the temporal and nasal meridians. The observers had normal color vision and a neutral outlying field equal in brightness to the test field was employed. The results as tabulated and plotted reveal marked irregularities in the increases of the thresholds in passing from the center towards the periphery. There are regions of low yellow sensitivity where there is no correspondingly low blue sensitivity, and the same is true for red and green. In their theoretical discussion (**33**) Ferree and Rand criticise previous investigators for employing stimuli equated in "canceling power" and determining the points at which the chromatic effects of these stimuli disappear, instead of measuring the sensitivities and chromatic sensitibilities for spectral stimuli at all points. Antagonistic colors may seem

to vanish at the same point when in reality there is a wide discrepancy between their thresholds, since a change in position of 2 or 3 degrees may cause a very large alteration in liminal value. They believe it to be impossible to find a red and green which do not vary in quality in passing from the center to the periphery, but it is not an essential of such a color theory as Hering's that such stable stimuli should exist. Although the ratios between the thresholds of antagonistic stimuli vary widely with position on the retina their "canceling powers" remain constant.

Houstoun (**53**) offers a restatement and amplification of his theory of color vision previously propounded. This theory is based upon the idea that monochromatic light falling upon the retina gives rise to a nerve current representative not of the frequency of this light alone but, to a lesser degree, of similar frequencies on either side of it in the spectrum, a result of the irregularities of molecular response in the photo-chemical process. The overlapping of such distribution curves for monochromatic red and green is thus able to produce practically the same distribution curve as that given by monochromatic yellow. A sufficient separation of two overlapping distributions, however, will produce two maxima with an accompanying effect of a complex sensation such as purple. The position of the summit of the curve, therefore, is representative of the hue, while its breadth stands for lack of saturation or resemblance to white. An important feature of this paper is a detailed analysis of the color sensation curves of Maxwell, Abney and König and Dieterici, which, for comparison, are reduced as far as possible to the same units. The data of Dieterici are adopted as most representative of the normal and a plot of these data on rectangular coördinates is employed as a basis for developing equations for the trichromatic color system, which are correlated with theoretical equations derived from the writer's hypotheses.

Barton and Browning (**11**) have investigated mathematically, and with the aid of models, the probable mechanism of the Young-Helmholtz theory of color vision. Three sample resonators of appropriate natural vibration periods were subjected to forced oscillation and their respective amplitudes of response were recorded photographically. The natural periods corresponded to 760, 550, and 400 $\mu\mu$ respectively, and the mathematical analysis showed that to produce the resonance curves required by the facts of color vision the vibrations must be very highly damped, this damping being so great that persistence of vision cannot

be explained as a result of the continued action of the vibrators after the removal of the stimulus. The theoretical resonance curves differ from those demanded by the facts in not having zero values for any wave-length and in that the red sensation curve shows no second maximum in the violet. The ratios of the responses of the three model vibrators to different impressed frequencies were found experimentally to correlate remarkably well with many facts of color vision, such as the results of mixing various monochromatic lights, fineness of color discrimination in various parts of the spectrum, etc. Lodge (**67**), Joly (**59**), and Allen (**4**) discuss the possibility that the response of the retina to light is photo-electric in nature. Lodge suggests that certain radio-active material which is contained in the pigment cells is set off by light, the resulting secondary rays stimulating the rods and cones electrically. Fatigue is attributed to exhaustion of the radio-active material. He suggests the experimental testing of this hyphthesis. Joly reviews two previous investigations of his own on the bullock's eye along this same general line which failed to produce positive evidence. Allen refers to the proposal previously made by him (*Journal of the Röntgen Soc.*, April, 1919) that the response of the rods and cones is due to a photo-electric action at their surfaces, which produces a change in electrical potential and thus generates a nerve impulse. Pikler (**77**) has propounded an elaborate theory of the chromatic and achromatic colors, which the reviewer has already summarized in a previous issue of the BULLETIN.

Sheard and McPeek (**88**) report extremly interesting measurements on the rest and action currents of the dog's eye. The problem which they attack is that of the existence of antagonistic influences which may be exerted upon the currents of the eye by lights of different colors. Spectral stimuli and a very reliable and delicate galvanometric system were employed. The eyes which were used were always freshly enucleated and care was taken to rest the preparations between exposures to different colors. Constant stimulation produced fluctuations in the nerve current of about 12 seconds period combined with a progressive change in the potential of the nerve stump with respect to the cornea, this change consisting in an increase in the positive potential of the nerve for the warm colors of the spectrum and a decrease for the cold colors, the turning point lying at about 600 $\mu\mu$. In the case of a yellow, 590 $\mu\mu$, a conflict of these two opposing tendencies was observable. Complementaries tended to reverse or to neutralize

the potential changes produced by each other. When a given potential level has been established by a certain color its complementary produces the greatest obtainable departure from this level. A plot of the potential conditions produced by different wavelengths shows in certain of its characteristics, striking similarity to the classical Hering color curves. The fluctuations in potential which were observed were not explicable on the basis of any external causes, and may possibly be related to the fatigue or after-image oscillation processes of the eye. A discussion of the history and theory of the electrical action of light in the retina is included.

Bard (7) points out that in hemianopia, color vision disappears more readily than form vision, indicating that perception of form is independent of that of color. He propounds the idea that on account of their length in the direction of propagation of the light the retinal rods and cones are able to record directly our impression of the depth dimension of visual space, the retinal image being not a surface but a solid. The pigment cells, lying alongside the rods and cones, serve to record the locus of the image within these receptor cells. The special function of the rods in the peripheral retina is to compensate for the aberrations of the refractive system in this region. Both rods and cones are supposed to be specifically sensitive to all of the colors because the limits of form and color perception are the same. The visual purple is regarded as the essential factor in color perception and its color is supposed to be determined by interference processes within the small disks of which the rods are composed, solutions of the visual purple being colloidal suspensions of rod fragments. Light tends to break up these disks or exert pressure upon them, different colors differing quantitatively in this action. The mechanism of color perception in the macula is attributed to a different process "qui m' a echappé jusqu'a present." Evidently most of the significant results of physiological optics have "escaped" this writer.

The year presents us with a number of interesting contributions to the knowledge of vision in animals. Hartridge (43) discusses the significance of the special shapes of the pupil in various animals. The pupil of the cat when partly closed has a longer vertical than horizontal axis, which favors the clear perception of vertical contours, these being of predominant importance to a climbing animal. In the case of the sheep the partly closed pupil has a longer horizontal axis, which harmonizes with the predominant importance of landscape contours for this animal. Being hunted rather than a

hunter it needs the increased peripheral illumination along the horizontal axis which is provided by the special pupillary shape.

Rochon-Duvigneaud (**83**) reports measurements of the positions and sizes of the foveæ in five species of *Rapaces diurnes*. The central fovea is usually smaller and deeper than in the case of the human being and the lateral is smaller and shallower than the central one. The thickness of the retina in the region of the foveæ is about 170 μ. In the buzzard the cones in the center of the central fovea are less than 1 μ in diameter but are 65 μ long, those of the lateral fovea being shorter. The author doubts whether the lateral foveæ in the bird have a binocular or stereoscopic function. He believes that each eye functions separately and that the foveæ of the single eye also act independently, much as do the fingers of the hand. In a second article (**82**) the same investigator gives further details regarding retinal structure in the same birds considered above. He finds that the colored oil droplets are smaller in the fovea than elsewhere corresponding with the decreased diameters of the cones. The colors found are yellow, orange and red, and their functions are probably to form a protective filter. The structure of the birds' fovea is in general finer and more complicated than that of the human being. In day-birds the rod-free region is larger than in man although the fovea itself is smaller. The ganglionic layer is very complex. In the *Rapaces nocturnes* there is only one fovea, which corresponds to the lateral fovea of the *Rapaces diurnes*, and in this there is as large a proportion of rods as in the remainder of the retina, although cones are also present.

Wager (**93**) reports experiments in which lumps of sugar were utilized on pieces of colored paper to test the chromatic vision of wasps. He finds that these insects are attracted by color and color contrasts. Minnich (**70**) finds that light stimulates the honey bee to movement, worker bees having a strong positive phototropism. When one eye is blackened the insects move in a loop in the direction of the functioning eye, these "circus movements" varying with the intensity of the light. The constancy of the circus movements shows that the arthropod eye is stimulated continuously by light, not requiring intermittent illumination. Eltringham (**31**) has studied vision in butterflies, paying particular attention to the nature of the image formed by the compound insect eye and the sensibility of the animals to colors and distances. He finds that objects are distinguished at distances from 3 centimeters to 1 meter from the eye, and contests the view of Hess that insects are color blind.

Hecht presents very interesting data concerning, and a keen theoretical analysis of the photo-receptor process in a mollusc, *Mya arenaria*. This animal (47) is sensitive to sudden changes in intensity of illumination but comes to a sensory equilibrium at any constant illumination. Its reaction time to light can be divided into two periods, a phase of "sensitization," which is followed by a latent period of 1.3 seconds, during which the stimulus can be removed without preventing the reaction. The laws of adaptation for the animal to any given light intensity can be represented by the formation of a chemical substance according to a bimolecular reaction. Sensory equilibrium is explained in terms of the stationary state of a reversible reaction involving this substance and two precursors. The corollaries of this hypothesis, that the reaction time at equilibrium and the rate of dark adaptation should vary inversely with the temperature were verified experimentally. The author's method of obtaining various sensitivity functions in terms of the length of the sensitization period is extremely neat and is based upon work described in a previous article on another mollusc. In a second paper (48) the same author treats of the nature of the latent period, this interval being too long to be attributed to pure neuro-muscular processes. Experiments made with dark-adapted animals show that if the "sensitization" period is defined as the minimal pre-exposure necessary to produce the minimal reaction time, the latent period will be found to vary inversely as the exposure. It therefore seems likely that the latent period is determined by an independent chemical reaction which is *catalyzed* by the presence of a substance formed during the pre-exposure period. The reciprocal of the latent period must represent the speed of the process which determines it, and this in turn must be proportional to the amount of catalytic substance formed. The essential element in the reaction of the animal to light is, therefore, the formation of a catalyzer or enzyme. The theoretical analysis is extremely keen and convincing. In a third article (49) Hecht considers further the effect of temperature on the latent period. He finds that for temperatures below 21° C. the relation is expressed by Arrhenius's equation but that above this temperature it increases more rapidly. This discrepancy is explained by the conception that the product formed during the latent period is inactivated by heat. The velocity of this inactivation is calculated from the experimental data.

Crozier and Arey (26) have studied the heliotropism of *Onchi-*

dium. In its normal environment the behavior of this animal is independent of light, but under artificial conditions it becomes negatively phototropic. Experiments show that a phototropic tendency exists but is inhibited in the natural environment, this being an instance of a definite response tendency which is non-adaptive in nature and which even tends to interfere with other adaptive actions. Hess (**51**) describes experiments on the vision of ten different species of crustacea. The writer's earlier results showed the same reactions to colored lights as in the color blind human being. The differential threshold for intensity in *Daphnia magna* is the same as for man. The writer claims to have determined "visibility curves" for certain crustacea with an accuracy as great as that obtainable for the human eye, by alternately illuminating the animals with homogeneous and heterogeneous light and noting the effect produced upon the swimming movements. The maximal sensitivity for *Daphnia* lies at approximately 525 $\mu\mu$ and equal responses are obtained at 650 and 450 $\mu\mu$ respectively. There is no Purkinje effect for these animals and in general they show no sensitivity to color or wave-length as such. Certain species of *Cladocera* are sensitive to ultra-violet light as far as 313 $\mu\mu$.

White (**98**) reports experiments in which mud-minnows and sticklebacks were trained to associate food with certain colors, demonstrating that these fishes can discriminate between red and both blue and green and also between yellow and green, although they are unable to differentiate between blue and yellow. To determine whether this discrimination is based upon apparent brightness rather than color, variations in intensity of the several colors were introduced without interfering with the discriminations. These variations were not very great, but the animals showed very little power to differentiate between different shades of gray. They also were unable to base associations upon peculiarities of stimulus pattern.

Arey (**5**) finds that in the case of two fishes and a frog the retinal rods remain in a shortened condition until an intensity is reached at which ordinary print can be read, while the cones remain elongated until colors can be distinguished. The thresholds for these responses therefore correspond with the utilitarian demands of the functions which they have hitherto been supposed to subserve, although other investigators have expressed doubt on this point.

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HEARING

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Stumpf (**22**) has recently made a careful investigation of vocalic sound. His work falls into three main divisions. With the aid of resonating forks, he has analyzed vowels uttered by the human voice and finds that the voice contains a much larger number of partials than had hitherto been suspected. In some cases he was able to detect a resonance of the 36th partial. The relative intensity of the various partials for each vowel was estimated, and the characteristic regions of resonance for each vowel sound thus

determined. All partials were found to belong to the harmonic series. As the fundamental appears also as a difference-tone of all the partials, its resonance is often much weaker than it appears as heard. In the second part of his investigation, Stumpf subjected the sung vowels to a more careful analysis with the aid of a large number of appropriately adjusted interference-tubes. This enabled him to eliminate the partials successively down to the fundamental, and then to add them gradually until the vowel sound was reconstructed. These experiments substantiated those of the introductory series, and, in addition, defined the characteristic formants or regions of resonance for each of the vowel sounds: *u*, *o*, *a*, *ä*, *ö*, *ü*, *e*, *i*. The formants in question are fixed regions of resonance ordinarily embracing an interval of a minor third. They remain fixed without regard to the fundamental tone upon which they are sounded; and hence they do not appear unless the fundamental contains the partials needed to establish the formant of the vowel in question. As constituted, the vowel sounds are entirely composed within the series of partial tones; there was never any sound left over after the interference with the partials was complete. All stages in the development of the sound upwards from the fundamental were found to be vocalic. Aside from *u*, the lowest of the vowels, each has its foundation in another vowel, as *o* in *u*, *a* in *o*, *ä* in *ao*, *e* in *o*, etc. While the specific character of the vocalic sound always rests upon a number of tones, the formants stand out as peculiar regions of resonance which distinguish the chief vowels from one another. The location of these regions is not such as to justify Köhler's octave law,[1] but is in remarkable agreement with other investigators, notably D. C. Miller[2] and H. Schole.[3] For *u* Stumpf finds a formant ranging downwards from g^1 to c, which usually coincided with the fundamental tone. The formant of *o* is at g^1, which now occurs as a partial, and not as a fundamental; for *a* the formant is at a^2; for *o* there are two formants, the primary lying at a^3, the secondary at g^1; for *a* the primary formant is slightly higher at $a\sharp^3$, the secondary formant lying at g^2; for *ü* the primary formant is again at $a\sharp^3$, the secondary formant being that of *u*, the fundamental, and ranging downwards from g^1; for *e* the primary formant lies at d^4 and the secondary at g^1, the sound embracing, as it were, the vowel *o*; while for *i* the primary formant is at b^4 with a secondary formant at e^4,

[1] *Cf. Zsch. F. Psychol.*, 1910, 58, 59–140.

[2] *Cf. The Science of Musical Sounds*, New York, 1916.

[3] *Cf. Arch. f.d. ges. Psychol.*, 1918, 38, 12–70.

and the whole embracing also the fundamental or *u* formant which ranges from g^1, downwards.

In a synthetic experiment in which artificial vowels produced by pipes and interference-tubes were compared with the sung vowels of a human voice, the artificial sounds proved to be more satisfactory to a majority of persons who did not know which was which, than were the sounds of the human voice. Supplemental experiments are cited to indicate that all spoken sounds, whether vowels or consonants, may be analyzed by these means into a series of partial tones with characteristic regions of resonance. Köhler's conclusion that the sounds of *sch*, *f* and *ch* pass beyond the normal range of hearing was not substantiated, for the last or highest of these could be produced within the region of a^4 to $b.^4$ In conclusion, Stumpf outlines three problems for further investigation. (1) How and under what conditions is it possible for a multitude of single tones to fuse into a unity that will give the impression of a vocalic sound? (2) How does the specific quality of the vowel relate itself to the characteristics of the partials which compose it? (3) How does the intensity of the total clang compare with the intensity of its constituent partial tones?

Perrett (**14**) criticizes the phonetic theory derived from Helmholtz, and, going back to Willis, contends that vowel sounds are gliding in nature and have nothing to do with the presence or absence of reinforced harmonics. The characteristic pitch of the chief vowels is, however, indicated; though the discrepancy between his results and those of Helmholtz and later investigators who have attacked the problem is marked. The fifth chapter of Perrett's book on *The Perception of Sound* has already been reviewed in this BULLETIN.[1]

Ogden (**13**) gives a graphic representation of the tonal manifold, indicating the range of tones from low to high each with its appropriate volume, inherent intensity and pitch-brightness. The discriminability of volume also indicates the basis of judgment for intervals and the position which the octaves take in the total series of tones. The possibility of brightness as an attribute is also discussed, in connection with the transition of sound from a tone of salient pitch to a vocalic formant of reduced brightness, but without alteration of pitch.

Smith and Bartlett (**20**) report upon the conditions of listening to sounds of weak intensity—results obtained in an investigation

[1] See Vol. 16, pp. 349–350.

of appropriate means for selecting candidates in the anti-submarine service. As the source of sound, both a buzzer and an electrically driven tuning fork were used. Binaural hearing proved better than uniaural, the best results being obtained with a small range of finely graded stimuli near the threshold. Weak sounds were sometimes found to require as much as 4″ in time to produce their full effect. There was little evidence of sensory fatigue; the sounds were often localized and sometimes seemed to move. Sound-stimuli were frequently perceived when they could not be heard; and the cessation of sound then gave rise to a positive experience of silence. Many other than auditory factors enter into theperception of weak sounds, and distracting sounds proved most detrimental to judgment when they were irregular of occurrence, similar to the sound listened for, or familiar to the observer. The subject's own estimate of his efficiency was likely to be accurate only when it was favorable; not when it was unfavorable. Piéron (15) gives some measurements of the latent time of sounds of weak intensity in listening to the buzzing of the lamella of a Hipp chronoscope. The sound was communicated telephonically to the observer, and its intensity reduced to a liminal value by increasing the distance of the observer from the instrument. The experimenter started the chronoscope, and at a given moment closed the circuit of the telephone. The observer was instructed to react in a way that stopped the clock as soon as he heard the sound. As the experimenter closed the circuit of the telephone, a slight click was produced which was heard by the observer after he had reacted to the whirring of the clock. The appearance of this secondary sound-stimulus in consciousness measures the latent time whose length is determined by a second reaction. The intensities of the primary sound were measured in multiples of the liminal intensity, and it was found that with the increase of intensity the latent time decreases from about 500σ at the threshold to about 200σ at 400 times this intensity. With still greater intensities the sound of the clock was masked by the sound of the lamella and appeared simultaneously with it.

Kovács (9) experimented upon music students in order to determine variations in ability to recognize errors in musical pieces and to reproduce by playing or singing what had previously been heard. He found the ability to recognize and the ability to reproduce fundamentally different. Recognition involves a passive attitude with attention upon the whole piece, whereas ability to reproduce in performance requires an active attitude with attention upon parts

and their serial order. The teacher of music is in need of the first-named ability, the virtuoso of the second. Those who study music chiefly for its cultural value should be trained more to the passive attitude of appreciative recognition, and can afford to devote less effort than is commonly required of them in accuracy of reproduction.

Schilling (17) describes four cases of deafness with attendant musical defects—both raising and lowering the apparent pitch in certain regions of the scale. Most cases of this kind may be referred to suppuration in the middle ear chamber, but since pressure on the round window could hardly explain defective hearing for definite regions of the scale, the author suggests an osmotic connection of exudations in the drum-cavity through the round window into the labyrinth which might occasion localized affections in the organ of Corti. Marage (11) after studying the coördination of the laryngeal muscles and their action in voice-production, concludes that the artificial timbre of the voice of the deaf is occasioned by a fixed position of the mouth in giving utterance to a particular sound, whereas in the case of persons who hear, the larynx alters its form with each note or vowel.

Zwaardemaker (26) classifies different types of apparatus designed to improve the hearing of deaf persons. They are five in number: (1) those that supply a means of conduction when the drum or ossicles have ceased to function; (2) apparatus to bring the source of sound nearer the ear; (3) apparatus to magnify the space from which vocables are apprehended; (4) apparatus to intensify the sound by resonance; and (5) apparatus to intensify the sound by transformation and magnification of its energy. In considering the use of each type of apparatus the individual needs of the deaf must be taken into account. When a very deaf person has forgotten how to listen to spoken sound, and supports his efforts by lip-reading, an apparatus which restores his hearing in some measure will be of little use without reëducation in listening. For minor defects of hearing where the patient is still able to distinguish whispered words at a distance of from one to two meters, much benefit can be derived from intensive practice in listening to whispered words in brief periods daily. In the experience of the author, the whispered word is a better source of sound in such cases than the artificial sounds of the vowel siren, for instance; but to be successful, training of this kind must be carefully supervised by an experienced physician. With various forms of apparatus designed

to bring the source of sound nearer, or to magnify the space and provide multiple resonance, care must be exercised with regard to the mean intensity of the sound as magnified, with regard to special zones of favored intensities which may either help or hinder the patient, and finally with regard to the often distressing reverberation produced by the apparatus in certain sounds which it modifies.

When a small number of holes is closed in the revolving disk of a siren and brief pauses occur between the sounding pulsations, secondary tones are produced by the interruption which are lower in pitch than the fundamental, and have been sometimes regarded as difference tones of subjective origin. Koch (**8**) has investigated the nature of the impulses that produce these sounds. With the aid of a manometric flame, as the generator of the sound, he finds that the distribution of energy, indicated by the appearance of the flame above and below the disk, produces these secondary pulsations in the same manner as the primary or fundamental tone. They arise through a lack of uniformity, or a disturbance occasioned by the alternation of the opened and closed stretches on the disk; and are an effect of friction. While the fundamental tone has its origin in the central portion of the flame, the secondary tones are produced at the outer edges of the flame, both above and below the disk.

In a series of communications to *Nature* (**2**) W. M. Bayliss has criticized Sir Thomas Wrightson's theory of the analytic mechanism of the ear,[1] and rejoinders have been made by Wrightson and his collaborator, Arthur Keith, together with additional comments by Lord Rayleigh, Wilfred Perrett and D. Fraser Harris.

Azoulay (**1**) records the case of a woman painter who upon hearing a noise in the dark invariably sees a flash of white light. The phenomenon does not seem to arise from the reflexive pressure of winking; for whenever pressure is exerted upon her eyeballs she sees vivid colors, but never white. Though very sensitive to both color and music, the subject has never experienced any other phenomena of color-hearing than the white flash described. The author regards the case as suggesting an elemental type of color-hearing.

Wittmaack (**25**) describes a series of experiments with guinea pigs in which the comparative effects of continuous sound stimulation and of continuous jars to the whole body of the animal were studied. The sound of a falling hammer whose pitch was in the region of the fourth octave produced, after two month's treatment,

[1] *Cf. An Enquiry into the Analytical Mechanism of the Internal Ear*, London, 1918.

noticeable changes in the organ of Corti near the base of the cochlea, both for animals resting on the same board which the hammer struck and for a second group resting upon an adjacent detached board. When the sound of the hammer was greatly reduced by allowing it to fall upon a felt mat, a degeneration of the nerve-fibers near the apex of the cochlea was produced after five or six months in those animals that rested upon the board receiving the jars, but no disturbance was found in the organs of the animals placed on the adjacent detached board. The conclusion is reached that many cases of gradually developing deafness among workers, such as railway engineers and firemen, who are subjected to constant jarring of the body, are produced in this manner, their deafness beginning with the lower register of the scale; whereas deafness produced by sound is more likely to begin with sounds of high pitch. Esclangon (5) notes that the sound of certain projectiles in artillery-fire gives no impression of pitch, and concludes that the effect of sudden variation of atmospheric pressure on the ears is a sort of manometric percussion without periods of resonance in accordance with which the organ of hearing is affected as a whole. In a brief paper Seashore (18) describes his new apparatus for measuring the acuity of hearing at any level of pitch. The apparatus consists of a motor-driven toothed wheel revolving about a stationary wheel likewise toothed. The speed is subject to control and measurement, and the vibrational frequency may thus be accurately determined. The sound, which is communicated by telephone with the ear, is varied in strength by allowing the current of the telephone to pass through a resistance-box. In this way the intensity of any tone within the range of hearing can be readily varied, and the acuity of hearing at any level of pitch quickly and accurately tested.

Hartley (6) reports a striking agreement between the theoretical location of a pure tone in terms of its phase-difference at the two ears, and actual tests of localization with a moving source of sound. Accurate judgment extended, in his experiments, only to tones of about 600 v.d. Beyond this frequency the judgment is confused by the appearance of secondary images of souud which may likewise be attributed to the influence of the phase-difference. He concludes that the localization of pure tones is more likely to be a result of the perception of phase than of cross-conduction within the head from one ear to the other. Stewart (21) returns to this question of sound-localization, bringing additional evidence for the perception of

phase-difference as the basis of judgment in locating the position of a pure tone. Experiments in which intensity was varied but phase was kept constant, gave evidence of difficulty in keeping the sound fused when the vibrational frequency exceeded 800 v.d. Even within this range the difference between the theoretical and experimental locations of a pure tone was found to be so great that one can hardly consider intensity to be an important factor. The logarithmic law of intensity-effects, previously reported by this author as a possible extension of Weber's Law,[1] is now regarded by him as merely a statement in terms of angular displacement of "the form taken by the recognition of the differences between the nature of these two nerve-responses" at the two ears. Experimenting with phase-differences and constant intensity, the author finds the apparent movement of a source of sound to be clearly defined for frequencies as high as 1,200 or 1,500 v.d. Above this level the sound-image becomes multiple and the judgment confused. With the lower rates of frequency, however, "the angular displacement from the median plane produced by a given phase-difference at the two ears proves to be the very position for the source of sound that will theoretically produce the aforesaid phase-difference at the ears." The effect of phase cannot be that of the time-interval involved, because equal time-intervals do not correspond to equal angular displacements except at higher frequencies. The conclusion is reached that the localization of sound is chiefly dependent upon a direct perception of phase. Cross-conduction through the skull mediates sounds of internal localization whose quality is quite other than that of sounds externally localized. As a crucial test of the relative importance of intensity and phase, Stewart cites the results of two of his observers who were quite unable to locate a sound of 1,024 v.d. when the intensity at the two ears was markedly different, though they did localize this tone with ease when there was a difference of phase.

Investigating the effect of amplitude upon electrically driven tuning forks Miller (12) finds that variation of amplitude seems to change the effective length of the fork, the frequency being lowered when the amplitude is increased. A formula is given to cover variations of this sort.

Dadourian (4) reports a variety of experiments upon conditions which affect the period of an electrically driven fork, such as the massiveness of the fork's base, a change in the constants of the

[1] *Cf. Psychol. Rev.*, 1918, 25, 242–251.

electrical current, an increase in the length of gaps between contact springs and points, amplitude, temperature, velocity of sound in the steel, the coefficient of elasticity, etc. Love and Dawson (10) report experiments with the Stern variator, and with an organ pipe, in which a change of air pressure, measured by a water manometer, with the corresponding alteration of intensity, measured by a modified Rayleigh resonator, showed that the intensity of sound varies almost directly with the blowing-pressure. With increased pressure the pitch of the variator rises, and in order to hold it at a fixed value the volume of the variator must be correspondingly increased. Knipp (7) reports that a mercury vapor-trap of pyrex glass—which is shaped like a test-tube with a transverse tube opening into it at right angles about half way up its length—will emit a clear pure tone from the side tube when the upper end of the main tube is stopped and the lower end is heated over a Bunsen burner. The tone remains constant in pitch, air being both received and discharged at the side tube. If extra side tubes are fused into the vibrating column, the pitch of the tone is raised; and when they are stopped, it is lowered. With tubes of different dimensions different pitches may be obtained which remain constant for an indefinite period if the heat is applied at a constant rate.

Watson (24) reports experiments with a rectangular megaphone constructed upon Rayleigh's theory that when a train of parallel waves passes through a slit whose width is equal to or smaller than half the wave-length, they spread out as if they came from the aperture as the center of disturbance. If, however, the width is large, as compared with half a wave-length, there is little or no spreading of the sound. When such a rectangular megaphone was used in an open space with its opening held vertical there was a diffraction of more than 90° in the sound of the voice, but when held horizontally, the speaker's voice was much less distinct to persons standing at the side.

Buck's *Accoustics for Musicians* (3) is a brief but comprehensive treatment of some of the chief principles of acoustics which an intelligent musician ought to know. The book is clearly written and includes many explanatory diagrams.

Pikler's (16) theory of consonance and dissonance has already received a special review in this BULLETIN,[1] as has Seashore's volume on *The Psychology of Musical Talent*[2] (19). Watt's new

[1] *Cf.* BULLETIN, 1919, 16, 350–352.

[2] *Cf.* BULLETIN, 1919, 16, 352–355.

book on *The Foundation of Music* (23) is reserved for similar treatment.

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NOTES AND NEWS

THE following items have been taken from the press:

PROFESSOR JAMES H. TUFTS, of the University of Chicago, will be visiting professor at Columbia University next year.

PROFESSOR W. M. URBAN, of Trinity College, has been appointed Stone professor of intellectual and moral philosophy at Dartmouth College.

PRESIDENT G. STANLEY HALL, of Clark University, and President Edmund C. Sanford, of Clark College, have both resigned. President Hall will devote his entire time to writing and to research. President Sanford will spend next year at the Johns Hopkins University and will then return to Clark University as professor of psychology and education.

DR. CARL C. BRIGHAM has been appointed assistant professor of psychology at Princeton University.

THE following grants for research have been made by the American Association for the Advancement of Science:

ONE hundred dollars to Mr. S. D. Robbins, of the Harvard Psychological Laboratory, for measurements of blood pressure of a trephined stammerer.

Two hundred dollars to Professor Daniel W. LaRue, Stroudsburg State Normal School, Pennsylvania, in support of experimental work on a phonetic alphabet.

Two hundred dollars to Professor Margaret F. Washburn, Vassar College, for a study of emotional characteristics of certain racial groups in New York City.

Two hundred dollars to Professor Joseph Peterson, George Peabody College for Teachers, Tennessee, in support of a study of the qualitative differences in the mentality of whites and negroes.

Two hundred dollars to Professor A. A. Schaeffer, University of Tennessee, in support of an experimental study of orientation and the direction of movement of animals, and particularly of the "spiral path" in man.

At a recent meeting of the American Philosophical Society, the afternoon of April 23 was devoted to a Symposium on Psychology in War and Education. The following papers were presented:

Introduction: Professor Lightner Witmer, University of Pennsylvania.

Methods: Dr. J. McKeen Cattell, editor of Science.

Psychological examining and classification in the United States Army; Robert M. Yerkes, National Research Council.

The relation of psychology to special problems of the army and navy: Raymond Dodge, Wesleyan University.

Relation of Psychology to the National Research Council: James R. Angell, National Research Council.

Psychological methods in business and industry: Beardsley Ruml, Philadelphia.

The individual in education: Arthur J. Jones, University of Pennsylvania.